The Effect of Dialect Variation and Hearing Aid Compression Type on Speech Recognition in Hearing Impaired Listeners

CAPSTONE PROJECT

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Abstract

It is well established that normal hearing listeners presented with speech spoken in an unfamiliar dialect demonstrate a reduction in understanding abilities. Although listeners with hearing-impairment are known to experience more struggles with understanding speech due to variability of the signal, little investigation of dialect understanding in hearing impaired listeners has occurred. Additionally, it is not known how amplification may assist the hearing impaired listener with understanding speech spoken in an unfamiliar dialect. Listeners with hearing impairment are likely to encounter speakers from different dialect areas on a regular basis in their daily lives. Therefore, it is important to establish how well hearing impaired listeners understand speech spoken in an unfamiliar dialect, and how hearing aids can be set to potentially maximize performance.

The present study examined the speech understanding abilities of hearing impaired listeners when presented with sentences spoken by a speaker from the Midlands dialect area, and the same sentences spoken by a speaker from the South dialect area. The sentences were presented in quiet and in noise. The performance of the hearing impaired listeners was compared with the performance of normal hearing counterparts. Results show that both groups of listeners performed poorer with the speech spoken by the non-native dialect speaker (i.e., the South dialect). The addition of background noise did not affect the normal hearing subjects' performance. However, the hearing impaired listeners performed poorer on speech presented in noise, regardless of the dialect. The effect of hearing impairment and background noise interacted to create disproportionately poorer performance in the hearing impaired group in noise.

The hearing impaired listeners were fitted with hearing aids in order for speech understanding abilities to be examined with fast-acting and slow-acting compression. The hearing impaired listeners were presented with the sentences in quiet and noise while wearing binaural hearing aids fit with fast-acting and slow-acting compression. Results indicate that no one compression strategy appears to improve speech understanding abilities more than the other across all listeners tested. It is possible that a slight advantage is seen with the use of fast-acting compression, but this difference is not significant. Variability in scores across subjects and small sample size may have contributed to the lack of difference in performance due to compression setup. Subjectively, however, each subject remained consistent on the compression strategy which they preferred. This suggests the importance of taking listener preference into account when adjusting compression settings, even if only for subjective acceptance.

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CHAPTER 1

Introduction

Sources of variability in speech, and the role they have in affecting speech understanding, have been the subject of numerous studies. Altering the qualities of speech, or the environment in which it is presented, has been shown to reduce performance on measures of speech understanding in normal hearing listeners. Previous examples of changes that reduce speech understanding performance include speech presentation level (Noordhoek, Houtgast, & Festen, 1999), speaker gender (Cornelisse, Gagne, & Seewald, 1991), speaker age (Cornelisse, Gagne, & Seewald, 1991), familiarity with the speaker's voice (Clopper & Pisoni, 2004) and the presence of background noise (Bashford, Riener, &Warren, 1992). Although the presence of a particular speech variable typically reduces speech understanding performance, normal hearing listeners can access other speech cues that may "repeat" information lost due to variation. These cues include frequency content of phonemes and context of the speech (Noordhoek, Houtgast, & Festen, 1999; Bashford, Riener, & Warren, 1992). The use of this redundant information allows for the preservation of some speech understanding abilities.

Listeners with hearing impairment are not able to benefit from the use of redundant information in speech in the same way as normal hearing listeners. The damage to the auditory system that reduces audibility in hearing impaired listeners also affects the frequency and temporal resolution of incoming speech, thereby preventing them from taking full advantage of redundant segmental information. Introducing variability to speech, especially in background noise, can negatively impact speech understanding in a more severe manner than that observed with normal hearing listeners. The speech understanding performance of hearing impaired listeners when variations in speech and environment are present have been studied extensively.

One speech variable that has received much attention in the literature in normal hearing listeners, but not in hearing impaired listeners, is dialect variation. When presented with speech in a dialect different from their own, normal hearing listeners have demonstrated poorer speech understanding performance in noise (Clopper & Pisoni, 2004; Clopper & Bradlow, 2008; Nabelek & Donahue, 1984). Changes to the speech signal caused by the difference in dialect occur on a phonological level. Unfamiliarity with these phonological differences can negatively affect the intelligibility of the speech. The amount of performance reduction can vary, depending on the environment in which the speech is presented, and the familiarity with the dialect being spoken. It is not known, however, how dialect variation affects speech understanding in hearing impaired listeners. Ferguson, Jongman, Sereno, and Keum (2010) examined how speech spoken by speakers with English as their non-native language affected understanding abilities in normal hearing and hearing impaired listeners. Not surprisingly, the hearing impaired listeners demonstrated more difficulties in understanding the speech spoken by the non-native English speaker, in comparison to the native English speaker, although it was shown to not be disproportionately poorer than the reduction in understanding observed in normal hearing listeners (Ferguson, Jongman, Sereno, & Keum, 2010). Additionally, no aided testing was performed with the hearing impaired listeners, and therefore, it is unclear how amplification may have improved speech understanding abilities in the listeners.

The purpose of the present study, then, was to examine the ability of normal hearing and hearing impaired listeners to understand speech spoken in their native dialect and an unfamiliar dialect. Sentence materials were spoken by two male speakers, one of whom was a native speaker of the same dialect spoken by the listeners (i.e., Midlands) and the other who spoke a dialect unfamiliar to the listeners (i.e., South). The sentences were presented to the listeners in quiet and in speech spectrum noise. The performance from both groups of listeners was then compared.

The present study also examined the affect amplification, particularly compression strategies, had on speech understanding abilities in the hearing impaired listeners. The hearing impaired listeners were presented with the sentences in quiet and speech spectrum noise while wearing binaural hearing aids fit with fast-acting and slow-acting compression. It was hoped that the present study would allow for a better understanding of how dialect variation affects speech understanding in hearing impaired listeners, and if changes in compression strategies would yield better results for those listeners utilizing amplification.

CHAPTER 2

Literature Review

The Communication Process

Human communication is a complex process that involves many variables. It is easy to take this process for granted, as humans utilize it countless times throughout their lifetime, but without the necessary components, communication cannot occur. Simply stated, communication involves a message that is transmitted from one participant to another. Numerous factors must be in place before this exchange can be attempted. The participants must have already spent the first years of their lives developing the ability to communicate and unless gestures and grunting is to be used, they must also speak the same language. One participant (the speaker) develops an idea that is to be expressed. Assuming the use of spoken language, these abstract thoughts are translated into sounds produced by the articulatory mechanisms of the speaker. These sounds (the message) can be described as sound waves, which are disturbances in air pressure, that travel to reach the second participant (the listener). The sound waves are collected by the auditory system and processed throughout several areas of the brain of the listener. Acoustically, the message is nothing more than sound energy containing varying levels of frequency and intensity information, which is not inherently meaningful. However, as they are processed by the listener, the sound energy is translated into meaningful phonemes, words and sentences, and interpreted into abstract ideas, thoughts and feelings, where they began in the mind of the speaker.

There are many places within the process of communication where information can be lost, misconstrued, or can vary. Factors interfering with effective communication can stem from the speaker, the listener, the message or the environment in which the message is spoken, and they often occur simultaneously from any number of these sources. Luckily, an abundance of information is transmitted from one listener to another during communication. Every piece of information that contributes to the meaning of the speech message does not need to be present in order for understanding to occur (Pinker, 1994). This fact is referred to as language redundancy and it allows for speech understanding to occur, even when some information is missing, incomplete or misunderstood (Bashford, Riener, & Warren, 1992).

Qualities relating to the speaker, listener, environment or language being spoken contribute to this redundancy of information. For example, the frequency energy present in speech is one such redundant characteristic. Although speech contains energy located at and above 10,000 Hz, it can be filtered to include only very narrow frequency regions (i.e., 600- 1600 Hz) and still be intelligible (Noordhoek, Houtgast, & Festen, 1999). A listener's familiarity with the speaker's voice is also redundant information. It is not necessary for a listener to be familiar with a speaker's voice to understand it, but in situations where communication is more difficult, this quality can aid the listener in understanding (Clopper & Pisoni, 2004). Rules pertaining to the language being shared from speaker to listener also accounts for redundancy, in that underlying knowledge of how sounds can be clustered and how words can be formed aid the listener in understanding by forming a "context" of sorts (Pinker, 1994). This context does not refer to the content of the message, but rather, an understanding between communicators that the message will utilize sounds, words and sentences permissible by the language and likely already encountered by the communicators. Knowledge of the context of the passage being shared also aids in understanding, although, once again, it is not necessarily mandatory for understanding to take place in a quiet environment (Bashford, Riener, & Warren, 1992).

Although redundancy of language information leads to amounts of unnecessary information, it becomes vital for message comprehension in less than ideal communication situations. Successful understanding can still occur, even if pieces of information are missing or unrecognizable, but it becomes more difficult (Bashford, Riener, & Warren, 1992). However, only so many pieces of information can be lacking before communication breakdown occurs.

Speech Variables and Effect on Understanding in Normal Hearing Listeners

Despite use of the same language, a plethora of variables present in the speech of all speakers can cause the speech signal to differ. Consequently, the speech spoken by different speakers is never exactly alike (Clopper & Pisoni, 2004). The variables that make each person's speech unique originate from the speaker's membership within social groups, such as socioeconomic status, ethnicity and geographical location, as well as the speaker's gender and age (Clopper & Pisoni, 2004; Cornelisse, Gagne, & Seewald, 1991). The emotional state of a speaker and their vocal effort can cause the speech signal to vary (Traunmueller & Eriksson, 2000). Additionally, each speaker possesses idiosyncratic features in their speech that causes their speech to sound different from others, even if the other speakers possess similar attributes as those listed above (Clopper & Pisoni, 2004). It is possible for listeners to identify the sources of variability in a speaker's speech. It has been shown that listeners can identify a speaker's gender, ethnicity and geographical location based on their speech alone (Clopper & Pisoni, 2004; Clopper, Levi, & Pisoni, 2005). However, it is not possible for these variables to be separated from the speech as it is processed by the listener (Clopper & Bradlow, 2008). In other words, even though listeners can identify these variables in speech, there is no way to actually remove them from the signal. Listeners who are accustomed to any variables present in a passage of speech will likely not find understanding difficult. In fact, this familiarity may help the listener understand, such as when the speech reflects a shared socioeconomic status between communicators, or the speaker is well-known by the listener. However, these variables can work against the listener, too. In this case, the presence of these variables negatively affects speech understanding.

For example, the gender of the speaker has been shown to change the amount of frequency energy present in the speech signal, particularly below 400 Hz and above 5000 Hz (Cornelisse, Gagne, & Seewald, 1991; Cox & Moore, 1988). Differences in frequency composition between male and female speech result from differences in the length, mass and tension of the vocal folds and size of the vocal tract (Titze, 1989). Adult male speech typically features a lower fundamental frequency (around 100 Hz) (Cornelisse, Gagne, & Seewald, 1991). The lower fundamental frequency present in adult male speech restricts the amount of frequency energy present in higher formants when compared to adult female speech. Female speech features a higher fundamental frequency (around 200 Hz) and therefore, larger amounts of high frequency energy are found (Cornelisse, Gagne, & Seewald, 1991). In particular, the location of spectral peaks for individual phonemes, which may be higher than those peaks found in male speech, contribute to greater amounts of high frequency energy present in female speech.

Frequency and intensity information found in speech can be altered based on the vocal effort of the speaker (Traunmueller & Eriksson, 2000). Changes in the fundamental frequency and harmonics of speech occur when speakers whisper, shout or use creaky voice (Traunmueller & Eriksson, 2000).

These changes also occur based on the amount of distance between speaker and listener and the presence of background noise; as the speaker alters the intensity level of their voice to overcome these environmental obstacles, the frequency content of their speech also changes (Traunmueller & Eriksson, 2000).

When examining speech understanding abilities, it is important to consider not only the variables present in the signal, but also the environment in which the message is spoken. Speech that contains any number of variables unfamiliar to a listener will become even more difficult to interpret when background noise or reverberation is present (Clopper & Bradlow, 2008; Clopper & Pisoni, 2004). A study conducted by Gengel and Kupperman (1980) demonstrated how speech understanding abilities decrease as a function of noise and variability in speech for normal hearing listeners. They presented six recorded versions of the CID-W22 word list, each of which was read aloud by a different speaker to normal hearing subjects. The list was presented monaurally to the subjects, along with noise. Even when subjects were familiarized with the word list, clear differences between intelligibility of the six speakers were demonstrated. The background noise not only prevented subjects from performing the speech understanding task as well as they would have in quiet, but the added variation in speech from the different speakers also contributed to poorer scores (Gengel & Kupperman, 1980). Similarly, Sommers, Kirk, and Pisoni (1997) demonstrated that listeners with normal hearing had better speech understanding performance in noise when one speaker, as opposed to multiple speakers, were used to present multiple trials of speech stimuli. Clopper and Pisoni (2004) argue that speech understanding abilities decrease as different speakers are utilized because the variability across speakers, along with the background noise, interact with one another to create more problems in understanding than if the variability or noise were to appear alone.

Dialect Variation

One speech variable that will be the concentration of the present investigation is dialect. Dialect refers to variations in speech due to the geographical origin of the speaker (Murray & Simon, 2006). Dialect variation can permeate many levels of speech, including phonological, lexical, and morphological structure (Murray & Simon, 2006). For example, regional variation can be expressed with differences in pronunciation of the same word (accent), use of multiple words to refer to one object (i.e., “pop”, “soda” and “coke” to refer to a sweet carbonated beverage) or differences in construction of plural second-person pronouns (i.e., “you guys” vs. “y’all” vs. “youzins”).

This paper will focus on phonological differences. Vowels are the main source of dialectal variation in American English at the phonological level (Clopper, Pisoni, & deJong, 2005). This includes differences in vowel length duration and differing formant frequencies of vowels (Clopper, Pisoni, & deJong, 2005). It is thought listeners utilize the information present at the first and second formant frequencies to identify vowels (Nearey, 1989). Therefore, differences in these formants caused by dialect variation interfere with vowel identification and increase the amount of overall speech variability, which decreases speech intelligibility (Bradlow, Torretta, & Pisoni, 1996).

Further attention is directed at two dialects of American English, the Midlands and South dialects. Descriptions of the regions in the United States where the dialects are spoken, as well as the dialect features themselves, are not mutually agreed upon by all researchers (Murray & Simon, 2006). However, a general overview is given. The Midlands dialect is generally considered to exist in a region spanning east from Nebraska and Kansas to Pennsylvania and stretching north from parts of Oklahoma and Arkansas along with the southernmost points of Missouri, Illinois, Indiana and Kentucky to areas south of the Great Lakes (Murray & Simon, 2006; Clopper, Pisoni, & deJong, 2005). The Midlands is characterized by the merger of [a] and [ɔ] (i.e., "cot" and "caught" are homophones), the fronting of [o] and [u] and the fronting and monophthongization of [aʊ] (i.e., [aʊ] becomes [a]) (Clopper, Pisoni, & deJong, 2005; Ash, 2006). The number of Midlands dialect features found in speech varies across different areas within the region (Ash, 2006). Cities located on the periphery of the Midlands dialect region, or in close contact with other dialect areas, do not exhibit many Midlands features (Ash, 2006). In contrast to peripheral cities, Columbus, Ohio is located within the middle of the Midlands area and is considered to contain many of the features of the dialect region (Ash, 2006). It is fair, then, to consider speakers indigenous to Central Ohio as speaking with a Midlands dialect.

As a dialect region, the South is typically defined as an area beginning in Texas at the westernmost border (Clopper, Pisoni, & deJong, 2005). The northern border of the region stretches across Oklahoma, Arkansas, Kentucky, West Virginia and Virginia to include all states south of these borders (Clopper, Pisoni, & deJong, 2005). As with the Midlands, the South is a large region and variations in dialect features across speakers do exist. However, the Southern Vowel Shift (SVS) has been described as a common feature noted in the speech of many Southern speakers (Clopper, Pisoni, & deJong, 2005). The shift describes a series of changes in the vowels of Southern speakers over a period of time, which today has resulted in raised [ɛ], lowered [e], and fronted [o] and [u], among other changes (Clopper, Pisoni, & deJong, 2005). One other feature found in the South include the loss of distinction between tense and lax vowels (i.e., the duration of [ɛ] becomes longer, making it more similar to the tense vowel [e]) (Clopper, Pisoni, & deJong, 2005).

Because the Midlands dialect is located geographically between the North and the South, the argument has been made that the Midlands dialect is not truly a distinct dialect, but rather a mixture of Northern and Southern features (Clopper, Pisoni, & deJong, 2005; Murray & Simon, 2006). Note, for example, the shared feature of [o] and [u] fronting between the South and Midlands. Despite the lack of agreement on the Midlands as a distinct dialect area, it is clear that Midlands speakers are different from speakers from the North and speakers from the South , even if they do share some of the same phonological features (Murray & Simon, 2006).

In regards to dialect, listeners must first be exposed to and learn any unfamiliar phonological variations before effective speech processing can occur (Clopper & Pisoni, 2004). Not surprisingly, it is well documented that speech understanding performance decreases when a listener is exposed to an unfamiliar dialect (Mason, 1946; Dahan, Drucker, & Scarborough, 2008; Clopper, Levi, & Pisoni, 2006; Clopper & Pisoni, 2004; Bradlow, Torretta, & Pisoni, 1996). In cases of listeners with normal hearing, significant struggles are not typical when attempts to understand the speech of a speaker using an unfamiliar dialect in a quiet environment are made (Clopper & Bradlow, 2008). In fact, normal hearing listeners may not exhibit any difficulties understanding an unfamiliar dialect in a quiet, reverberant-free listening environment (Clopper & Bradlow, 2008). However, when background noise and increased reverberation are added to the environment, further degrading the already unfamiliar speech signal, a decrease in speech understanding is observed. Speech presented to listeners in the same dialect they speak will be degraded, but the speech of an unfamiliar dialect will be harder to understand (Clopper & Bradlow, 2008). For example, Clopper and Bradlow (2008) exposed a group of normal hearing listeners to a less ideal environment by presenting sentences in four different dialects in conjunction with varying levels of speech noise. As the level of the noise increased, the speech intelligibility of all dialects, even those familiar to the listeners, decreased. The effect of an unfamiliar dialect on speech understanding was more pronounced when higher levels of noise were present (Clopper & Bradlow, 2008).

Speech Variables and Effect on Understanding in Hearing Impaired Listeners

Because normal hearing listeners experience greater difficulties with understanding speech spoken in an unfamiliar dialect (Clopper & Bradlow, 2008), it can be expected that this variation in speech will also negatively affect speech understanding in those listeners with sensorineural hearing loss.

The study of speech variables does not necessarily consider the integrity of the listener's auditory system when speech understanding abilities are discussed. It is important to consider, however, how an impaired auditory system can affect understanding, both with and without speech variability. Hearing loss can prevent the listener from being able to detect, discriminate, or comprehend the spoken message, and consequently, speech understanding will be negatively affected. Sensorineural hearing loss impacts an incoming speech signal in several ways. The reduction in hearing sensitivity limits the audibility of the speech signal, especially in frequency regions where the hearing loss is moderate or more severe. However, this type of hearing loss also affects how frequency and intensity information in the speech signal is processed (Strelcyk & Dau, 2009). Frequency selectivity of the auditory system becomes less fine tuned, which causes a "smearing" of the multi-frequency speech signal (Strelcyk & Dau, 2009). The temporal structure of the speech signal is distorted, in a similar manner as frequency information (Strelcyk & Dau, 2009). The ability of the impaired auditory system to distinguish two sounds as being separated in time diminishes. Therefore, a reduction in audibility of some sounds prevents the hearing impaired listener from receiving all parts of the speech signal, and the speech information that does reach the auditory system cannot be processed as effectively. In quiet environments, these factors typically do not greatly affect speech understanding, especially when audibility can be restored via the use of amplification (Strelcyk & Dau, 2009). However, the effect of these factors does become evident when noise is added into the background (Strelcyk & Dau, 2009; Humes, 1991; Zurek & Delhorne, 1987). Reduced audibility and distortion of frequency and temporal cues interact to create speech understanding difficulties in noise, although how much each factor contributes to the problem is not as clear. When examining hearing impaired listeners under the age of 50 with no more than moderate sensorineural hearing loss, reductions of speech understanding abilities have been noted in noise (Zurek & Delhorne, 1987). The authors attributed the reduced performance (when compared to the same subjects' speech understanding in quiet abilities) primarily to the reduction in audibility from the hearing loss and the interference caused by the noise (Zurek & Delhorne, 1987). However, it is likely that the distortion of frequency and temporal cues also contribute to poorer speech in noise performance (Strelcyk & Dau, 2009). This may be true especially for older adult listeners, those with more severe degrees of sensorineural hearing loss or certain individuals who have poorer speech understanding abilities than would be predicted from pure tone thresholds (Zurek & Delhorne, 1987; Humes, 1991).

Assessment of speech understanding in hearing impaired listeners as a function of speech variability is not common. Little is known about how hearing impaired listeners understand speakers with an unfamiliar accent. Subjective reports from hearing impaired individuals note substantial difficulties understanding speakers whose speech is accented (Ferguson, Jongman, Sereno, & Keum, 2010). These difficulties arise when speakers have a different native language or dialect from the listener (Ferguson, Jongman, Sereno, & Keum, 2010). Ferguson, Jongman, Sereno, and Keum (2010) demonstrated that the difficulties with understanding accented speech experienced by hearing impaired listeners is not disproportionately greater than those difficulties experienced by normal hearing listeners, but that the difficulties contributed to poorer speech understanding, especially when the speech signal was degraded by noise or reverberation.

Amplification

Amplifying sound with a hearing aid allows for speech to become audible by presenting speech to the user above their hearing thresholds (Payton, Uchanski, & Braida, 1994; Plomp, 1994). The frequency response of a hearing aid can be adjusted to fit the hearing loss configuration of the wearer and apply appropriate amounts of gain where it is needed. Additionally, hearing aids utilize different features, such as directional microphones, noise reduction and feedback cancellation algorithms to further enhance the incoming speech signal for better understanding (Dillon, 2001). Unfortunately, despite these features and the technological advances that aim to improve their performance, amplification devices cannot perfectly replicate the function of a healthy auditory system. Even when audibility is restored across the band of speech frequencies, decreased frequency and temporal resolution prevent full utilization of the auditory information being sent to the hearing impaired listener (Moore, Peters, & Stone, 1999). Damage to the auditory system, in particular the cochlea, is associated with loudness recruitment, further complicating the relationship with increased audibility and speech understanding, as many listeners with sensorineural hearing loss cannot tolerate loud sounds (Dillon, 2001).

Nevertheless, speech understanding in environments free of background noise and reverberation can be excellent for listeners who are hearing impaired and using amplification (Strelcyk & Dau, 2009). The relationship between increasing audibility of sounds and speech understanding becomes more complex in less ideal listening environments (Payton, Uchanski, & Braida, 1994; Plomp, 1994). For those individuals who are hearing impaired and using amplification, greater difficulties with understanding speech in noise in comparison to their normal hearing peers are observed (Nabelek & Donahue, 1984). As stated above, the understanding of speech spoken in an unfamiliar dialect in noise decreases for normal hearing listeners (Clopper and Bradlow, 2008). Because speech variability can create difficulties with understanding, it can be expected that individuals with hearing loss will also struggle with understanding speech spoken in an unfamiliar dialect. Listeners must hear and learn the phonological variations present in an unfamiliar dialect before speech processing can occur (Clopper & Pisoni, 2004). However, a listener with hearing loss may not be able to hear or distinguish the variations, even if aided with amplification. Results from Ferguson, Jongman, Sereno, and Keum (2010) demonstrated that listeners with hearing loss struggle more to understand foreign-accented speech in quiet and in noise. It is likely, then, that listeners with similar amounts of sensorineural hearing impairment will perform poorer on measures of speech understanding when listening to an unfamiliar dialect than their peers with normal hearing. It is unclear, however, if an interaction between unfamiliar dialect and noise may be present.

Understanding speech in noisy environments is one of the biggest challenges faced by individuals with hearing impairment (Plomp, 1994). Many decades ago, individuals with hearing loss did not benefit much, if any, from wearing hearing aids in noisy environments, as hearing aids simply amplified all incoming sounds (Plomp, 1994). As hearing aids became more sophisticated, and with the introduction of digital technology, techniques for improving speech understanding in noise were developed. Most techniques aim to increase the signal-to-noise ratio. Increasing the signal-to-noise ratio involves increasing the intensity of the incoming speech, decreasing the intensity of the present environmental noise, or both. In turn, speech becomes easier to hear and therefore understand (Plomp, 1994). Directional microphones, noise reduction algorithms, and compression are technological features currently used to help increase the signal-to-noise ratio in hearing aids (Plomp, 1994). These features help to improve speech understanding in noise for hearing aid users, but they do not eliminate the problem of noisy environments (Plomp, 1994; Dillon, 2001).

Compression Strategies

Compression adjusts sounds coming into a hearing aid, which have a wide range of intensity levels, to fit the reduced dynamic range of the hearing aid user (Dillon, 2001). This involves increasing the intensity level of soft sounds, so that they are above the hearing thresholds of the user, as well as reducing the intensity of loud sounds, and keeping the intensity of speech as audible as possible, all while remaining distortion-free (Dillon, 2001). Speech must be made loud enough for the user to hear it, and for it to overcome as much environmental noise as possible, but it must also remain at an intensity that is comfortable to the user and that will not damage any residual hearing (Plomp, 1994). Although the use of compression in hearing aids has made it possible for more input to reach the hearing impaired ear, it does alter the natural intensity relationships between sounds. This change in intensity characteristics distorts the signal, which can create further problems in speech understanding

(Kuk, 1996).

There are several aspects of compression that can be manipulated differently in order to achieve the goal of maximum speech understanding, including threshold, range, ratio, number of channels and attack and release times (Plomp, 1994; Dillon, 2001). Compression threshold is defined as the lowest intensity level for an incoming sound that will invoke a compression response from the hearing aid, while compression range refers to the range of intensity levels where compression will take place, from the threshold to a defined maximum level (Dillon, 2001). When an incoming signal that is more intense than the threshold enters the hearing aid, the sound is automatically compressed. The amount of compression superimposed onto the signal depends on the compression ratio; this describes how the intensity level of the input is changed by compression before gain is added and then sent to the listener (Dillon, 2001). The compression ratio is defined as a ratio because it compares the decibel level of the input and the resulting compressed output. For instance, a compression ratio of 3:1 states that for every 3 dB of input coming into the hearing aid, only 1 dB of output is being delivered to the user (Dillon, 2001). As the intensity of a sound changes, the amount of compression does, as well; typically, the more intense an incoming signal is, the greater the compression ratio, and therefore, the more compression that is applied to the sound. As the input reaches the maximum output of the hearing aid, the compression ratio becomes as high as 10:1, in order to sharply limit the amount of gain coming from the hearing aid, without causing severe distortion to the sound (Dillon, 2001).

In order to more accurately reflect the configuration of a particular hearing loss, hearing aids separate signals into multiple frequency bands, or channels that can be individually adjusted. These multiple channels are also used to apply differing amounts of compression inside each frequency range (Dillon, 2001). Each channel can begin employing compression at differing thresholds, ranges and ratios. Attack and release times refer to how quickly compression in a hearing aid is turned on and off once an incoming sound has met the criteria for compression. In other words, attack time describes how quickly input is changed by compression, and release time refers to how quickly the compression turns off, once the input has been changed to an acceptable intensity level (Dillon, 2001). Variation in how these aspects of compression are set reflect differing philosophies on maximizing speech understanding, and allow for the creation of diverse types of compression.

Slow-acting compression is defined by the use of long attack and release times (Plomp, 1994). Slow-acting compression amplifies the incoming speech signal in a similar way to linear amplification, which better maintains the spectral and intensity cues naturally found in speech than fast-acting compression (Plomp, 1994). It can also contribute to higher user satisfaction, due to the lower amount of distortion associated with this compression type. In combination with a low compression threshold, which would require the hearing aid to compress incoming speech signals most of the time, slow-acting compression can theoretically allow for good speech understanding (Kuk, 1996).

Fast-acting compression, on the other hand, uses fast attack and release times in order to alter the intensity differences between consonants and vowels of an incoming speech signal (Dillon, 2001). This reportedly helps compensate for the effects of recruitment found in those with sensorineural hearing loss (Plomp, 1994). It has been suggested that increasing the intensity of consonants in a speech signal, in order to match the intensity of the adjoining vowels, leads to increased speech understanding because it allows for better audibility of the consonants while preventing the adjacent vowels from also increasing in intensity and masking the consonants (Dillon, 2001). This is especially true in listeners with intact cognitive abilities or good frequency resolution (Lunner & Sundewall-Thoren, 2007). Fast-acting compression is often used in multi-channel hearing aids, along with a moderately low compression threshold (i.e., 50 dB SPL) and a low compression ratio (2:1) (Kuk, 1996). When used in this regard, it is considered wide dynamic range compression (WDRC) (Kuk, 1996). Fast-acting compression also aims to normalize loudness in hearing impaired listeners, which in theory may contribute to better speech understanding, as normalizing loudness should allow for better audibility of the speech signal (Kuk, 1996).

It has not been made clear which type of compression provides superior speech understanding, especially in regards to specifications for attack and release times. Since the advent of digital technology in hearing aids, researchers have tried to determine which compression strategies provide optimal speech understanding (Cox & Xu, 2010; Hansen, 2002; Moore, Peters, & Stone, 1999; Plomp, 1994). Research from Plomp (1994) and Hansen (2002) suggest that multi-channel, slow-acting compression with release times longer than four seconds allows for maximum speech understanding, because of the preservation of spectral and intensity cues naturally found in speech. Fast-acting compression, on the other hand, allows for larger intensity differences between vowels and consonants to exist, which may assist hearing impaired listeners in phoneme identification (Dillon, 2001). However, no one compression type has been identified as being superior to another in a consistent manner. Many subjects have even been shown to prefer linear amplification over compressed output (Kuk, 1996). One concern over the use of slow-acting compression is the amplification of impulse sounds, which, if release times are slow, would not be effectively reduced in gain (Kuk, 1996). However, in today's hearing aids, algorithms designed to prevent amplification of impulse sounds, without reducing overall gain, are employed. Newer technological developments such as these may help determine if any compression type is superior in maximizing speech understanding.

Certainly, not all hearing aid users will benefit from one particular compression type (Cox &

Xu, 2010). For instance, there is evidence that users with a mild to moderate sensorineural hearing loss may benefit more from fast-acting compression (Kuk, 1996), while users with impaired cognitive abilities may struggle with this type of compression (Lunner & Sundewall-Thoren, 2007; Cox & Xu, 2010). Both types of compression can allow for a speech signal to be delivered to a user's ear that is audible, comfortable and distortion-free, which are the main goals of compression. However, the correlation between audibility of sounds, comfort, cognitive abilities, speech understanding abilities and best compression type is not direct. It appears that determining the best type of compression involves many complicated factors (Cox & Xu, 2010; Kuk, 1996).

Additionally, the subjective preference of the hearing aid user is also a factor in determining what type of compression is most appropriate to use. Users have been shown to consistently choose one type over another, even when no advantages in speech understanding are noted between differing compression types (Cox & Xu, 2010; Kuk, 1996). Many subjects have even been shown to prefer linear amplification over compressed output (Kuk, 1996). Factors such as comfort, ease of listening and cognitive abilities may influence a user’s rating of compression type (Cox & Xu, 2010). These factors will likely differ among hearing aid users (Cox & Xu, 2010).

Purpose of the Study

It is clear that hearing impairment interferes with speech understanding, especially when the speech is degraded by noise or reverberation. Normal hearing listeners also experience reductions in speech understanding abilities when speech is presented in noise or reverberation, as well as when linguistic characteristics of speech, such as an unfamiliar dialect, are present. Although it is expected that listeners with hearing impairment would experience more difficulties with understanding speech spoken in an unfamiliar dialect than speech spoken in their native dialect, as is the case with normal hearing listeners in noisy environments, there is little data to support this conclusion. It is not known if hearing impaired listeners will experience a decrease in speech understanding abilities in both quiet and noise with speech spoken in an unfamiliar dialect, and how large of a reduction in speech understanding abilities will be observed. Additionally, it is unknown if there are particular hearing aid settings that can allow for maximum speech understanding ability of an unfamiliar dialect.

There are many questions that prompted this research study. It is not clear how speech spoken in a non-native dialect will affect speech understanding in hearing impaired listeners. How well can hearing impaired listeners understand an unfamiliar dialect? How much difference in speech understanding abilities will be noted when words of an unfamiliar dialect are presented in a quiet environment versus a noisy environment? How do these listeners compare to their normal hearing peers? In order to answer these questions, the following experiment was proposed. The current study examined two aspects of dialect understanding in hearing impaired listeners. The purpose of the first experiment was to determine the amount of difference in speech understanding ability between a group of normal hearing listeners and a group of hearing impaired listeners when listening to two word lists that differed in dialect: 1) the listeners' native dialect, and 2) an unfamiliar dialect. Recognition performance was also measured in two conditions: in quiet and in noise. It was hypothesized that the normal hearing listeners and hearing impaired listeners would perform equally well when listening to speech spoken in their native dialect in quiet, but that the normal hearing listeners would outperform the hearing impaired listeners when listening to speech spoken in the non-native dialect in quiet. It was further hypothesized that the normal hearing listeners would have significantly better speech understanding scores than the hearing impaired listeners when listening to both their native and non-native dialect word lists in noise.

A secondary purpose of the study was to investigate how recognition performance of dialects improved with the use of hearing aids. Compression is a hearing aid feature commonly used to maximize speech understanding, but there are many different types and it is unclear which can maximize the understanding of an unfamiliar dialect. Experiment 2 examined how speech understanding performance for hearing impaired individuals varied when listening to their native dialect and an unfamiliar dialect while using two different hearing aid compression settings in noise. One setup used slow-acting compression and the other setup used fast-acting compression. It was hypothesized that the hearing impaired listeners would obtain significantly higher speech understanding scores when their hearing aids employed fast-acting compression as opposed to slow-acting compression. This is due to the fact that each set of stimuli only differed based on phonetic variations imposed by the different dialects of the speakers of the speech stimuli. It was believed that the difference in phonemes provided by fast-acting compression would allow for the greatest contrast of the sounds and therefore, better speech understanding.

CHAPTER 3

Methods

Subjects

Ten adults between the ages of 18 – 50 years (mean = 31 years, standard deviation = 9.7 years) participated in the present study. Adults under the age of 50 years were chosen in order to minimize risk of cognitive decline due to aging from interfering with speech understanding abilities (Wiley, et al., 1998). The subjects were divided into two groups based on their hearing thresholds, which were measured in all subjects prior to testing. Group 1 consisted of five adults (2 male and 3 female) with normal hearing. Normal hearing was defined as hearing thresholds ≤ 25 dB HL for 250-8000 Hz. Group 2 consisted of five adults (3 male and 2 female) with bilateral mild to moderately-severe sensorineural hearing loss. Bone conduction thresholds were within 10 dB of air conduction thresholds at 500-4000 Hz for both groups. The average audiogram for both groups is presented in Figure 3.1.

Average Pure Tone Thresholds for Subjects

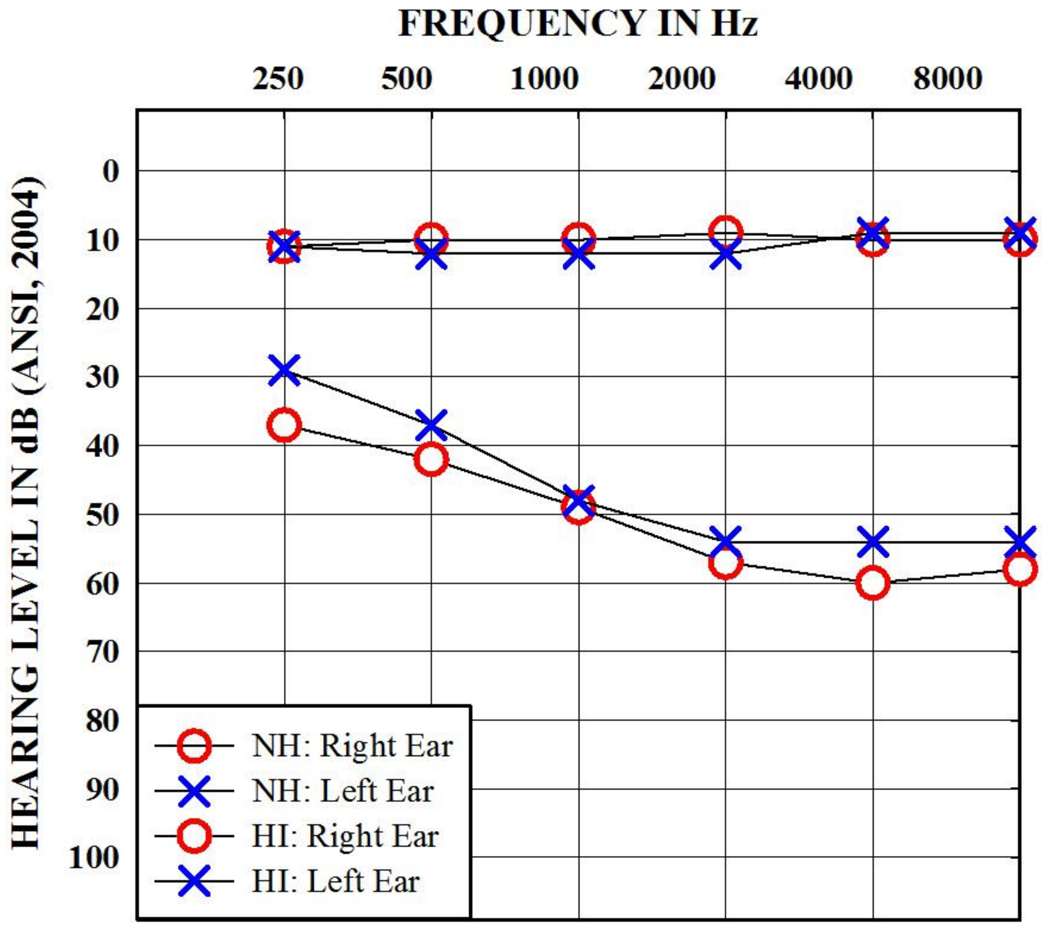

Figure 3.1: Average pure tone thresholds for NH and HI subjects (n = 10).

All subjects in Group 1 had normal outer and middle ear function, as exhibited by normal otoscopy and tympanometry (ASHA, 1990). All subjects in Group 2, except for one, exhibited normal outer and middle ear function. One subject in Group 2 with a history of middle ear pathology did present with higher than normal compliance, but these results did not affect pure tone thresholds. Speech recognition thresholds were within 10 dB of the pure tone average for all subjects. Average speech understanding scores for CID W-22 monosyllabic-words in quiet (Hirsh, et al., 1952) were 99% for Group 1 (at 50 dB HL) and 92% for Group 2 (at MCL). Additional inclusion criteria for Group 2 included use of hearing aids for at least 6 months prior to the experiment.

All subjects were recruited from the Ohio State University (OSU) student population, the OSU Speech and Hearing Clinic, and the surrounding community of Columbus, Ohio. All subjects lived in central Ohio (i.e., the Midlands dialect area) for the majority of their lives and were monolingual speakers of American English. Subjects from Group 1 participated in one session, whereas subjects from Group 2 participated in two sessions. All subjects were paid for their time. The present study was approved by the Biomedical Sciences Institutional Review Board at OSU.

Materials

The stimuli consisted of eight sets of 14-15 sentences. Three to four keywords were present in each sentence, with 44 key words in each set of sentences for a total of 352 key words. Each set of sentences was recorded by two speakers representing two distinct dialect areas. One speaker spoke with a Midlands dialect (Central Ohio), while the other spoke with a Southern dialect (North Carolina).

The sentences were taken from the Revised Bamford-Kowel-Bench Standard Sentence Test

(Bent & Bradlow, 2003). The sentences use simple subject-verb-object construction and are semantically acceptable to English speakers. The object keywords of some sentences are highly predictable (i.e., “The cook is making a **cake**”), while other keywords have low predictability (“She found her **purse**”) (Bent & Bradlow, 2003). Individual stereo tracks were created for each set of sentences using Adobe Audition 1.0 and recorded on compact disc (CD). The sentences were recorded on one channel and speech spectrum noise was recorded on the other channel. Ten samples of speech spectrum noise were paired with the individual sentences in a counterbalanced manner. The sentences were centered within the noise sample so that the noise played for 1-second prior to sentence onset and 1-second after sentence offset. A 5-second interstimulus interval was used between each sentence and a 1000 Hz calibration tone was recorded as track 1 of the CD. The calibration tone, sentences and noise were normalized for total RMS.

Procedures – Experiment 1

All ten subjects participated in Experiment 1. Prior to testing, the audiometer and loudspeakers were calibrated according to the appropriate American National Standards Institute (ANSI, 2004) standards for loudspeaker output. The sentence stimuli were presented in the sound field in two conditions: in quiet and in background speech spectrum noise. The subjects were seated in the sound booth 1 meter away from the two loudspeakers. The sentences were presented from the loudspeaker located at 0° azimuth and the speech spectrum noise was presented from the loudspeaker located at 180° azimuth. The sentence stimuli were delivered from a CD player (Sony CE375) routed through an audiometer (Interacoustics AC33) and presented at 50 dB HL for Group 1 and at MCL for Group 2.

MCL was determined in the sound field using live voice presented to the front loudspeaker prior to sentence testing. For the background noise condition, the speech spectrum noise was presented 8 dB below the level of the speech (+8 dB SNR).

Each subject listened to four sets of sentences, preceded by a four-sentence set of practice sentences in quiet. Two sentence sets were presented in each condition, quiet and background noise. For each condition, one set of sentences was from the Midlands speaker, and one set of sentences was from the Southern speaker. The order of presentation of quiet versus background noise as well as the order of presentation of Midlands versus Southern speaker was counterbalanced across subjects. Subjects were required to repeat each sentence and the key words in each sentence were scored correct or incorrect. Percent correct scores were calculated for each sentence set, based on the maximum score of 44 key words.

Following testing, earmold impressions were taken on subjects from Group 2, in order to order earmolds for Experiment 2.

Procedures- Experiment 2

Subjects from Group 2 only participated in Experiment 2. The subjects were fit binaurally with Starkey S-Series 11 behind-the-ear hearing aids and tested with the sentence stimuli utilized in Experiment 1. The subjects were tested with two sets of sentences in quiet and two sets of sentences in background noise in two differing compression setups. Two sentence sets in each noise condition allowed for the presentation of one sentence set from each speaker. Testing for Experiment 2 was performed two weeks following the first visit, so as to minimize any learning effect of the stimuli and to allow earmolds to arrive for fitting.

Prior to each subject's arrival, the pure tone thresholds obtained at the previous visit were entered into NOAH and the Fonix 7000 system.. The hearing aids were programmed to the subject's hearing loss using Starkey's proprietary software. Upon subject arrival, the earmolds and hearing aids were fit. Prescriptive gain targets were calculated and measured using Fonix7000, based on NAL-RP fitting rationale. Gain settings in the hearing aids were adjusted during real ear insertion gain (REIG) in order to match prescribed targets. Subjective comments were also utilized when setting gain targets, in order to ensure speech was audible, comfortable and tolerable. Gain settings were verified using Fonix 7000 in both compression setups, as differences in gain can be observed based on the compression type used.

The sentence stimuli were presented in the same environment as Experiment 1. The sentences were presented at 50 dB HL and the noise was presented at 42 dB HL (+8 dB SNR). The order of presentation of sentence sets was counterbalanced across subjects. Care was taken to avoid presenting sentence sets in the same pattern as in Experiment 1 for each subject to minimize learning effects. A percent correct score based from a total correct score of 44 was calculated for each sentence set. Following sentence testing, subjects were asked to subjectively rate each setup in quiet and in noise, based on understanding, comfort and ease of listening.

The two compression setups were identified as Setup A and Setup B. Multi-channel compression was utilized in both setups. The compression thresholds varied across channels in each setup, but averaged to approximately 50 dB SPL, which is considered the intensity level of soft speech. An attack time of five seconds and a release time of five seconds was used in Setup A (slow-acting compression). These settings are based on the research of Keidser and Grant (2001) and Hansen

(2002). An attack time of 15 milliseconds and a release time of 50 milliseconds were used in Setup B (fast-acting compression). These settings were based on Keidser and Grant (2001) and Dillon (2001).

CHAPTER 4

Results

Data Analysis

Prior to conducting statistical analysis, the percentage data were transformed into rationalized arcsine units (RAUs) (Studebaker, 1985). This transformation was undertaken so as to minimize variance associated with percentage data. The data from Experiment 1 were analyzed using a repeated measures analysis of variance with *group* as the between-subjects variable, and *condition* (quiet vs. noise) and *stimulus type* (Midlands vs. South) as within-subjects variables. In order to uncover any details on significant results obtained with the repeated measures ANOVA, post hoc analysis was performed. Data from Experiment 2 were not statistically analyzed, as the number of subjects in Group 2 (n=5) was not large enough to perform ANOVA with three variables. Individual subject results are discussed.

Experiment 1 Results

Average speech recognition performance data on the sentence task in Experiment 1 are displayed in Figure 4.1 and in Table 4.1 for subjects in Group1 (NH) and Group 2 (HI). Figure 4.1 displays the mean performance on the sentence task for each subject group in all four conditions, while Table 4.1 displays the mean and standard deviation values.

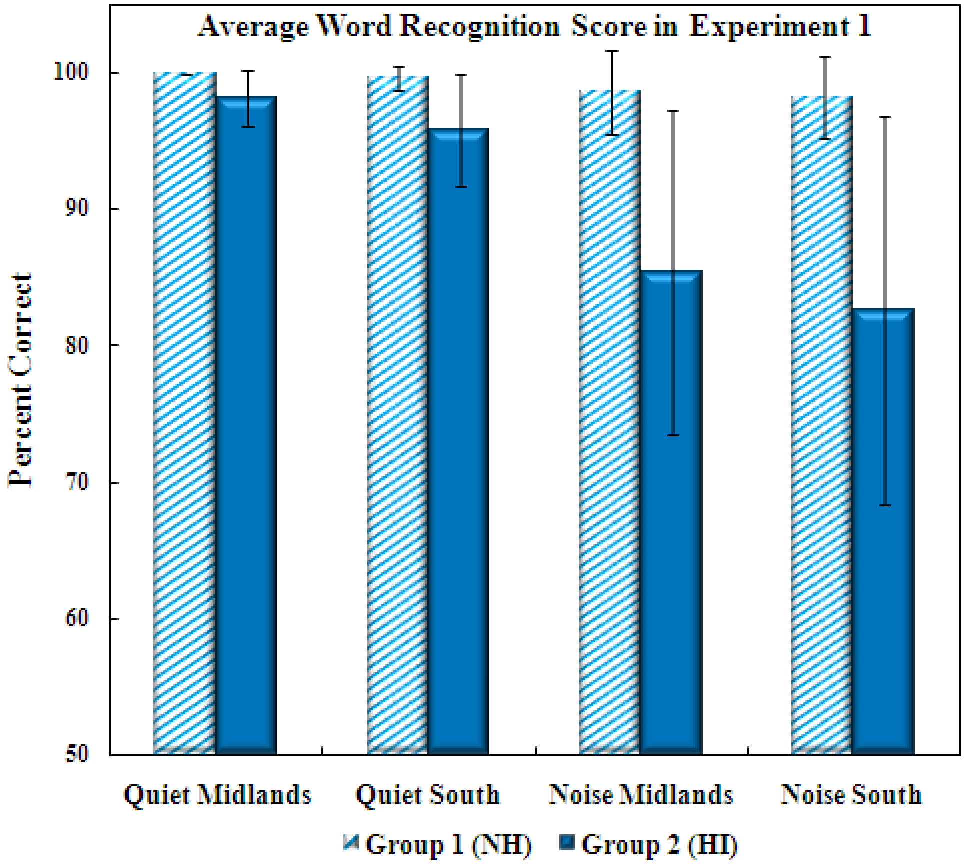

Figure 4.1: Average word recognition score for NH and HI subjects for all listening conditions in Experiment 1. Error bars indicate standard deviation about the mean.

Table 4.1: Mean and Standard Deviation Values from Experiment 1.

	Group 1 (NH)				Group 2 (HI)			
	Quiet Midlands	Quiet South	Noise Midlands	Noise South	Quiet Midlands	Quiet South	Noise Midlands	Noise South
Mean (%)	100	99.6	98.6	98.2	98.2	95.8	85.4	82.6
St Dev (%)	0	0.9	3.1	3.0	2.0	4.1	11.9	14.3

As can be seen from Figure 4.1, Group 1 (NH) demonstrated better performance on the sentence task than Group 2 (HI) in both quiet and noise. A repeated measures analysis of variance (ANOVA) revealed a significant main effect of group on performance ($F_{1, 8} = 9.5$; $p < .05$). In other words, overall performance observed in Group 1 (NH) was significantly better than the performance observed from Group 2 (HI).

Stimulus type, specifically the test speaker dialect, had an effect on results as well. A significant main effect for stimulus type was noted ($F_{1, 8} = 6.1$; $p < .05$). The Midlands speaker yielded better recognition performance than the Southern speaker in both groups of subjects.

A significant main effect for noise condition was noted ($F_{1, 8} = 28.8$; $p < .05$). Post-hoc analysis (one-way ANOVA) revealed significant differences in performance between the quiet and noise conditions for Group 2 only. The hearing impaired group exhibited significantly poorer recognition performance in the noise condition than the quiet condition for both the Midlands and South stimuli. The interaction between subject group and noise condition was also significant. Taken together, the results of these analyses show that the normal hearing subjects performed better on the speech understanding task than the hearing impaired group. However, for both the hearing impaired and normal hearing subjects, listening to sentences spoken in an unfamiliar dialect yielded lower speech understanding performance than when stimuli were spoken in the subjects' native dialect. For the normal hearing subjects, noise did not have a significant effect in changing performance, no matter which dialect the sentence stimuli were spoken. The hearing impaired subjects, on the other hand, were affected by noise, and performed worse in this condition when listening to stimuli spoken in both dialects. The hearing impaired subjects performed disproportionately poorer than the normal hearing subjects in noise.

Experiment 2 Results

Average speech recognition scores from Experiment 2 are displayed in Figure 4.2 and means and standard deviation are displayed in Table 4.2 below. Please recall that setup A refers to slow-acting compression and setup B refers to fast-acting compression.

Because statistical analysis could not be performed on the data set from Experiment 2, it is not possible to draw conclusions about the amount of difference between performance in the noise, stimulus type and hearing aid setting conditions. Some impressionistic differences in the overall performance of subjects are noted, however. Performance between stimuli type appears to remain similar within the same noise condition (i.e., Quiet Midlands and Quiet South; Noise Midlands and Noise South), but performance in noise as compared to quiet is lower. The subjects do not appear to perform better in one compression setup over the other. Therefore, performance only appears to change depending on the addition of noise, with little changes seen in performance between dialects or compression setups. However, it is noted that variation in performance (as denoted by standard deviation) is larger for subjects in noise within both dialect types when they are fit with Setup B, as compared to performance in noise with both dialect types in Setup A.

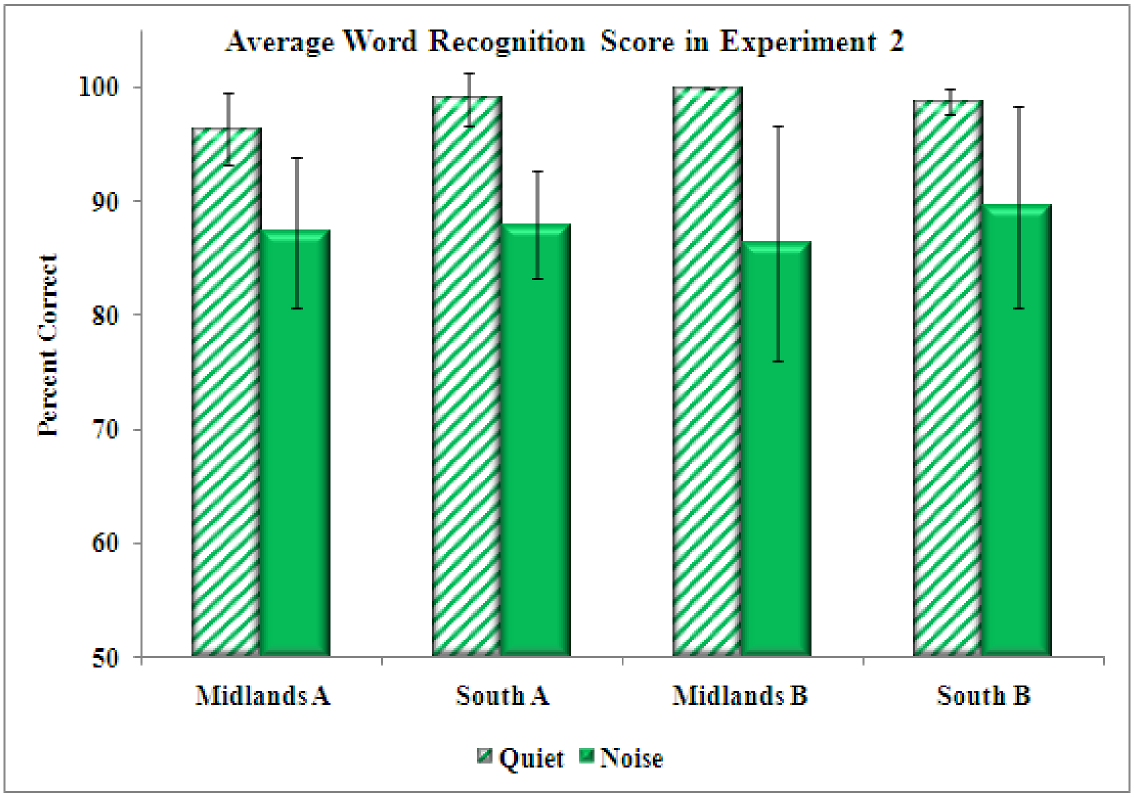

Figure 4.2: Average word recognition score for HI subjects for all listening conditions in Experiment 2. Error bars indicate standard deviation about the mean.

Table 4.2: Mean and Standard Deviation Values for Experiment 2. Group 2 (HI) only.

	Setup A				Setup B			
	Quiet Midlands	Quiet South	Noise Midlands	Noise South	Quiet Midlands	Quiet South	Noise Midlands	Noise South
Mean (%)	96.4	99	87.4	88	100	98.8	86.4	89.6
St Dev (%)	3.2	2.2	6.6	4.8	0	1.1	10.3	8.9

Experiment 2 Individual Data

As mentioned above, individual subject scores for Experiment 2 are discussed, in lieu of statistical analysis. Table 4.3 displays the percent correct score on the speech understanding task for Experiment 2 for all five HI subjects. From Table 4.3, it is possible to see that HI4 appears to have performed better with both dialect types in Setup B than in Setup A. All other subjects do not show consistently better scores in both noise and stimulus type conditions across hearing aid setups, though. In regards to the Midlands dialect, subjects HI4 and HI5 appear to have slightly better performance in Setup B than Setup A, while subject HI3 appears to have a better score in Setup A, and subjects HI1 and HI2 performed equally well in both setups. Similar differences between subjects can also be seen for the South dialect. HI1 and HI5 appear to have performed slightly better in noise with setup A, HI2 and HI3 performed equally well in both setups and HI4 appears to have performed better with setup B in noise. It does not appear that any clear pattern of superior performance with one setup over the other is emerging.

Individual subject speech recognition scores were plotted within each condition, in order to determine if superior performance could be observed in one condition over another. Figure 4.3 displays data comparing Quiet and Noise performance, Figure 4.4 displays data comparing Midlands and South performance and Figure 4.5 displays data comparing A and B performance. Note that for each scatterplot, all data points are divided into four categories, which denote the other two conditions. For example, Figure 4.3 uses the Quiet and Noise conditions to compare data and the data points are separated based on Midlands A, Midlands B, South A and South B conditions. Some data points overlap with one another, so all 20 points are not always visible in the figures.

Clear improvements in speech recognition scores are noted in Figure 4.3 for subjects when performing the sentences task in quiet rather than in noise. It does not appear that stimulus type or compression setup affects performance in Figure 4.3, which is not surprising, since better performance in both stimulus types and compression setups would be expected in quiet, as compared to noise. However, the analyses of stimulus type and compression setup are not so clear. As shown in Figure 4.4, it does appear that most subjects performed slightly better in the South dialect with compression setup A while slightly better performance was noted with compression setup B for the Midlands speaker. Subjects HI2, HI3, HI4 and HI5 performed better with the Southern speaker in the Quiet A setup as compared to the Midlands speaker. Subjects HI1, HI2 and HI4 performed better with the Southern speaker in the Noise A setup, as compared to the Midlands speaker. Subjects HI3 and HI4 performed better with the Southern speaker in the Noise B setup, while the other subjects performed better in the Noise B setup with the Midlands speaker.

In regards to compression settings, 10 trials were completed with better scores in the B (fast-acting compression) setup, 6 were completed with better scores in the A (slow-acting compression) setup and 4 trials were completed with equal performance between the two setups. It does not appear that stimulus type or noise condition affected which compression setup allowed for better performance. As can be seen from Figure 4.5, data points from all four conditions represent best performance for both compression setups. Subjects HI2, HI3, HI4 and HI5 performed better in the B setup in the Quiet Midlands condition. Subject HI4 performed better in the B setup in the Quiet South condition as well. Subjects HI1, HI2 and HI5 performed better in the B setup in the Noise Midlands condition, and subjects HI4 and HI5 performed better with B in the Noise South condition.

Table 4.3: Individual speech recognition scores (percent correct) for Experiment 2 [n = 5].

	Midlands A		South A		Midlands B		South B	
Subject	Quiet	Noise	Quiet	Noise	Quiet	Noise	Quiet	Noise
HI1	100	89	100	93	100	90	98	84
HI2	98	86	100	89	100	89	98	86
HI3	98	82	100	80	100	73	100	80
HI4	93	82	95	89	100	80	98	100
HI5	93	98	100	89	100	100	100	98

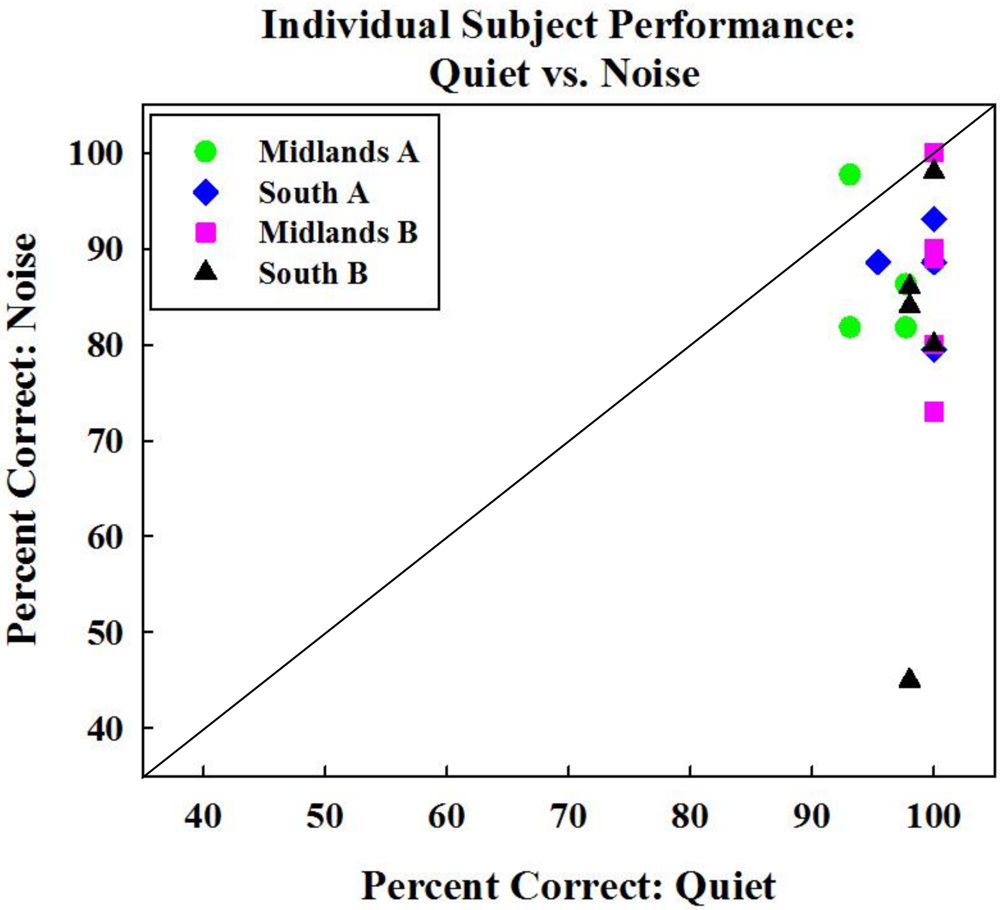

Figure 4.3: Comparison of individual subject performances based on Quiet and Noise conditions

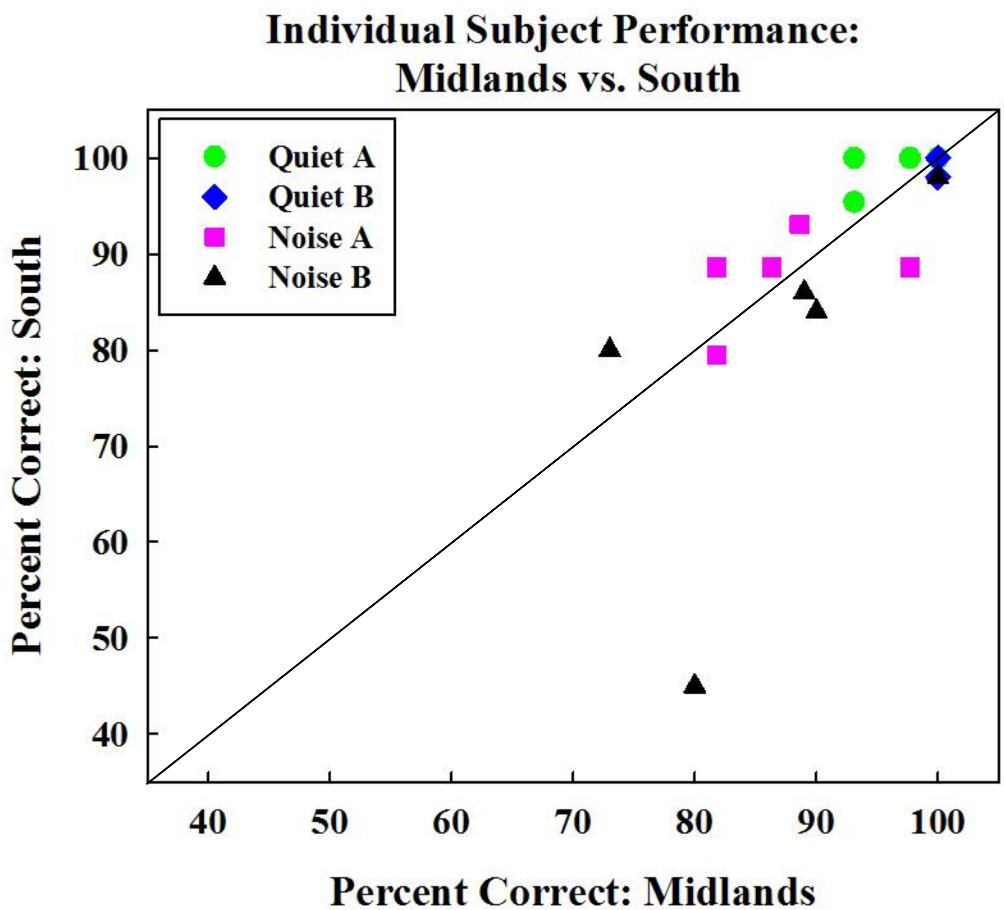

Figure 4.4: Comparison of individual subject performances based on Midlands and South conditions

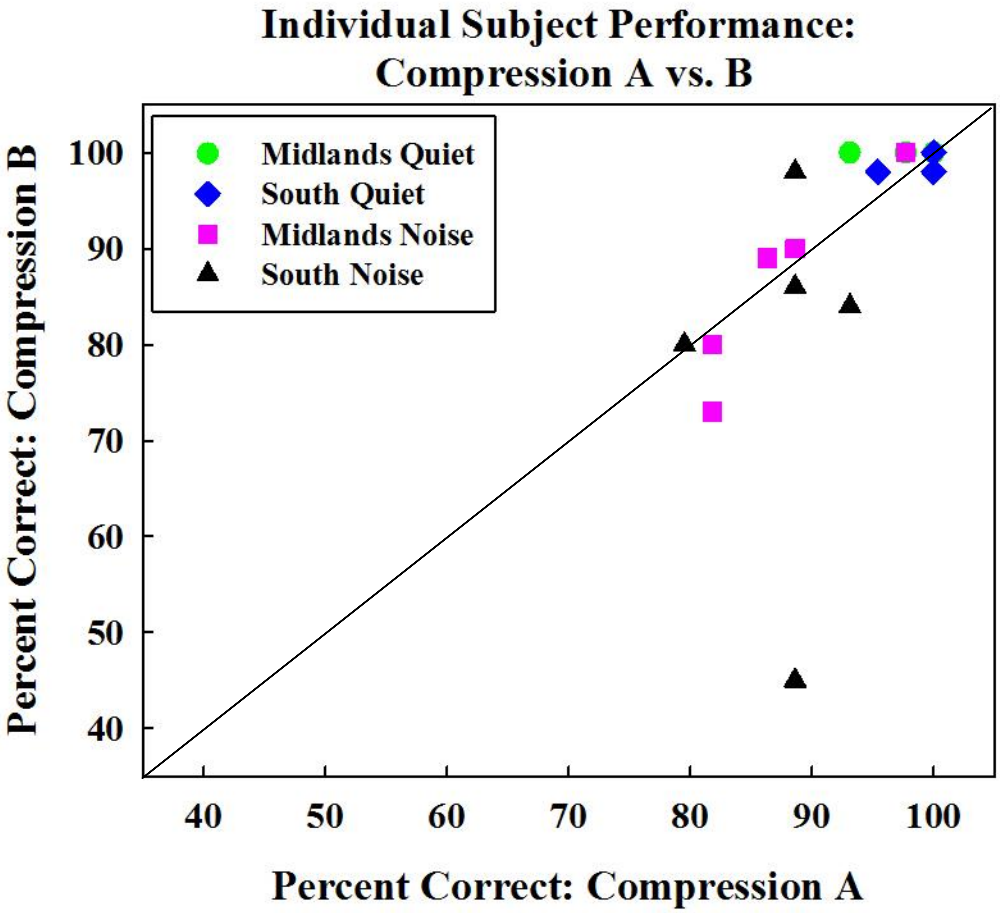

Figure 4.5: Comparison of individual subject performances based on Setup A and Setup B conditions

Experiment 2 Subjective Ratings

The subjective ratings on the hearing aid settings given by the subjects in Group 2 are displayed below in Table 4.4. The ratings are based on the overall understanding, ease of listening and comfort for all sentence sets used during testing. The ratings were given by each subject following all testing in Experiment 2; therefore, the ratings apply across all stimulus types and noise conditions.

In order to determine if subjective rating and subject performance appeared to correlate, the performance of each subject on Experiment 2 was plotted based on their scores in the A hearing aid setup and the B hearing aid setup. Subjective ratings based on understanding were used to split the subjects into two groups- one which preferred setup A (HI1, HI3 and HI5) and the other which preferred setup B (HI2 and HI4). Understanding ratings were used, because all subjects had a clear preference for either A or B. Figure 4.6 displays the data below.

A total of 20 points (5 subjects x 4 sentence set tasks) can be observed in Figure 4.6. Out of the 12 performance points that represent subjects who preferred setup A, 3 show better performance in setup A, 5 show better performance on setup B and 4 show equal performance between setup A and setup B. For the 8 performance points that represent subjects who preferred setup B, 3 points show better performance in setup A and 5 points show better performance in setup B. It does not appear that choosing one compression type based on ease of understanding allows for a subject to necessarily perform better in that setup. It is possible that for those subjects who preferred setup B, slightly better performance in setup B is demonstrated, but this observation is only based on impressionistic findings.

In order to determine if subjective rating and subject performance appeared to correlate, the performance of each subject on Experiment 2 was plotted based on their scores in the A hearing aid setup and the B hearing aid setup. Subjective ratings based on understanding were used to split the subjects into two groups- one which preferred setup A (HI1, HI3 and HI5) and the other which preferred setup B (HI2 and HI4). Understanding ratings were used, because all subjects had a clear preference for either A or B. Figure 4.6 displays the data below.

Table 4.4: Hearing aid settings preference for HI subjects.

Hearing aid setting preference based on:	HI1	HI2	HI3	HI4	HI5
Understanding	A	B	A	B	A
Ease of listening	A	B	A	no preference	A
Comfort	no preference	B	A	no preference	A

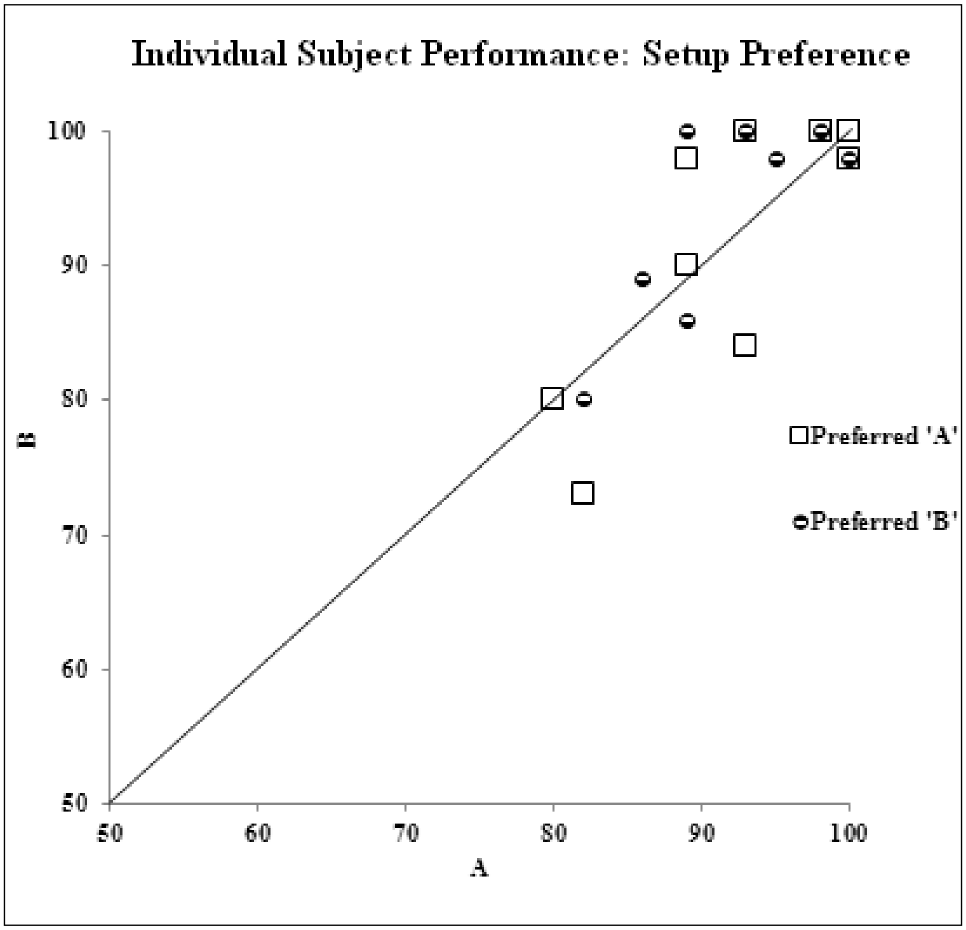

Figure 4.6: Subject performance on Experiment 2 based on subjective rating for Understanding

CHAPTER 5

Discussion and Conclusions

The aim of this study was to shed some insight into how hearing impaired people are able to understand unfamiliar dialects as compared to normal hearing listeners. Compression setups, namely attack and release times, were investigated to determine which were more beneficial for speech understanding, if a clear advantage exists. Little research has been reported on hearing impaired listeners and their abilities to understand speech spoken in a non-native dialect. Because the difference in dialect can impose more difficulties in understanding speech, it is important to better understand the speech understanding abilities of hearing impaired listeners (Ferguson, Jongman, Sereno, & Keum, 2010). This information can contribute to a better overall understanding of how hearing impairment affects speech understanding, and can potentially lead to more effective use of hearing aid technology to overcome these difficulties.

Experiment 1

It was hypothesized that the normal hearing listeners and hearing impaired listeners would perform equally well when listening to speech spoken in their native dialect in quiet, but that the normal hearing listeners would have significantly better speech understanding scores than the hearing impaired listeners when listening to the non-native dialect in quiet. Additionally, the normal hearing listeners were hypothesized to outperform the hearing impaired listeners with both the native and non-native dialect word lists in noise. The results from this study confirm the hypothesis that the normal hearing and hearing impaired subjects would have similar performance in quiet with the sentences spoken by the Midlands speaker. The significant differences in performance noted between the normal hearing and hearing impaired subjects with the Southern speaker in quiet also confirm the hypothesis.

The results from Experiment 1 appear to confirm results already observed in previous studies. Normal hearing and hearing impaired listeners had more difficulties in understanding a speaker with a non-familiar dialect, as observed in Clopper and Bradlow (2008) and Ferguson, Jongman, Sereno, and Keum (2010). Significant differences were noted within and between both groups of subjects. The subjects differed in overall speech understanding performance based on group; in other words, subjects with hearing loss performed significantly poorer than those subjects with normal hearing. The normal hearing subjects performed differently based on stimulus type, with worse performance noted with the Southern speaker. These results for the normal hearing listeners are not surprising; based on the research from Clopper and Bradlow (2008), it was expected that the normal hearing subjects would not perform differently between stimulus types in quiet. Clopper and Bradlow (2008) also report poorer performance with understanding speech spoken by speakers with non-native dialects in noise. Subjects with normal hearing did not perform significantly worse in noise than in quiet. This may be due to the +8 dB SNR used in the study. Use of a more difficult SNR, such as +2 dB or 0 dB, may have yielded even larger differences in performance based on stimulus type in the normal hearing subjects.

The hearing impaired subjects demonstrated significantly poorer performance in Experiment 1 based on both stimulus type and noise condition. Their performance in noise was poorer for both the Midlands and Southern speaker and performance decreased in both quiet and noise for the Southern speaker. Additionally, the hearing impaired group demonstrated disproportionately poorer performance in noise than their normal hearing counterparts. These results confirm the hypothesis that the hearing impaired subjects would perform worse in noise than the normal hearing subjects with both dialects. The significantly poorer performance in noise based on hearing impairment has been observed in previous studies, such as Zurek and Delhorne (1987). An interaction between condition and stimulus type was not observed in either group. The results from Ferguson, Jongman, Sereno, and Keum (2010) confirm the results found in this study. As with the results from this study, the normal hearing subjects performed better than the hearing impaired subjects with the foreign-accented speech understanding task and the hearing impaired listeners did not perform disproportionately poorer in noise when compared to the normal hearing listeners (Ferguson, Jongman, Sereno, & Keum, 2010).

Experiment 2

In regards to speech understanding performance using two different compression setups, it was hypothesized that fast-acting compression would allow for better speech understanding of the unfamiliar dialect, because it was thought the fast attack and release times would allow for more contrast between phonemes in the speech stimuli.The results obtained in Experiment 2 are pilot data, and the strength of any observations made from the data is limited. Two main points emerge from the subjects' performance, however. First, it does not appear that performance between stimulus types differs significantly when the subjects were aided. This point does not necessarily address which compression type (A or B) was used, but rather, that the discrepancies in performance between stimulus types disappear once the subjects are fitted with amplification. Previous data on aided subject performance on native and non-native dialect speech understanding is lacking, and therefore, it is difficult to compare the results from this study to any others for consistency. It is possible that hearing aid use in the subjects may have allowed for similar speech understanding abilities no matter which dialect they heard. However, it is also possible that the speech understanding task was too easy, evidenced by the overall average score for Experiment 2 of 93.2%. If these results do reflect expected hearing aid performance in the real world, and not a ceiling effect of the task, the results are promising for hearing aid users who encounter speakers from differing dialect areas. In this case, the addition of noise would likely decrease speech understanding in real life, as was observed in this study.

Second, a slight difference does appear to exist between compression types, in that setup B demonstrated better performance than setup A. Recall that setup B refers to the fast-acting compression type. However, this difference is not consistent across subjects. Average change in performance from setup A to setup B shows better performance in setup B for three of the four conditions. There may be a slight advantage to the use of fast-acting compression in the hearing impaired subjects from this study. The largest difference in performance from setup A to setup B within each subject's performance is 3.4%, but it is not known if this difference is significant. Subjectively, the subjects differed on which type of compression setup they preferred. Once again, a slight correlation between preference of setup B for ease of understanding and better performance with setup B may have been observed. It does not appear that a correlation between preference of setup A for ease of understanding and better performance with setup A exists.

The lack of strong patterns in the data from Experiment 2 has also been observed in previous discussions and studies concerning speech understanding and compression types. Hansen (2002) and Plomp (1994) report use of slow-acting compression will lead to better speech understanding abilities, while Lunner and Sundewall-Thoren (2007) suggest fast-acting compression will allow for better speech understanding, at least in users with intact cognitive abilities. Indeed, hearing aid manufacturers differ in the compression type they utilize in their products, as universal agreement on the superiority of fast-acting or slow-acting compression over the other has not been established. Although there may be an advantage to using fast-acting compression for the group of subjects in the present study, slow-acting compression also yielded high scores on the sentence task, which may indicate more about the ease of the overall task, and not so much identify one compression type as being superior over another.

There was no one compression setup that was subjectively preferred by all HI subjects, although each subject remained consistent in which setup they preferred based on comfort and understanding. Listener preference for one type of compression, despite no advantages for speech understanding between types, has also been reported by Kuk (1996). Subjects from the present study reported additional comments about the compression types. HI1 stated he preferred setup A because it was “louder,” but that he had to use a great deal of effort to understand speech in noise with both setups. HI2 mentioned that although he preferred setup B, he felt his own hearing aids were more comfortable and required less strain for speech understanding. HI3 preferred setup A because the hearing aids did not sound as “muffled” as they did in setup B. She also mentioned that the hearing aids sounded similar to her own aids when in setup A, which she liked. HI4 had the most difficulty in deciding which setup he preferred; he felt both setups were very similar, although he slightly preferred setup B for understanding. He stated that both setups had better sound quality than his own aids, which are several years old and are employing maximum gain settings. HI5 stated background noise was easier to block out with setup A. From the subjective ratings, and the variety of reasons the subjects reported for choosing which compression setup they preferred, it is possible to see that choosing one type of compression for all hearing aid users would likely be detrimental to user acceptance of amplification. Subjective reports from hearing aid users should be considered in choosing the best amplification settings for each user.

When interpreting the results of this study, it is important to keep several points in mind. It is very difficult, if not impossible, to perfectly replicate real-world communication situations which may be encountered by listeners, whether they are normal hearing or hearing impaired. Therefore, this study may not accurately predict real-world performance, especially in hearing impaired subjects where difficulties with understanding speech arose once noise was added. The speech-weighted noise utilized in this study is not typical of noise sources found in real-world environments, and other variations in speakers, such as rate of speech or gender could affect speech understanding abilities. These results should not be applied to performance expected in real-world environments.

Despite the fact that neither compression type yielded drastically different performance, it is clear that speech understanding performance did improve for both dialects when the subjects were aided. One important takeaway point from this study would be the importance of amplifying listeners with hearing impairment. This study suggests that compression type is not as crucial of a choice, as long as the hearing aid output is audible and comfortable.

Limitations

There are numerous limitations to this study that further warrant caution when interpreting the results obtained during data collection. Although the group of subjects was well balanced in terms of gender and age, and homogenous in their history of living in Central Ohio, the small subject size reflects one major limitation in interpreting the results of this study. It prevented statistical analysis from being performed in Experiment 2 and limits the conclusions that can be drawn from the study, as relating to the general population.

The age limitations to the subject group were utilized to prevent any cognitive deficits from interfering with speech understanding abilities in the subjects. However, the subjects may have been “too” good; this likely resulted from their young ages, mild to moderate degree of hearing impairment and the +8 SNR used with the speech in noise. If this study were redone, the age group of the subject would remain the same, but listeners with more severe degrees of hearing loss may be chosen and a more difficult SNR, such as +5 dB or 0 dB, would be utilized during testing. Speech babble noise, as opposed to speech-weighted noise, may also increase the difficulty level of the task by more closely mimicking the speech signal, allowing for a clearer view of the hearing impaired subjects’ abilities. The study could also utilize a separate group of older adult subjects with the same degree of hearing loss as the younger adults, to determine if age has any influence on the study performance.

In the future, it is hoped that data can be collected with more hearing impaired subjects. An increase in sample size would perhaps reveal more concrete conclusions regarding compression type and dialect understanding.

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